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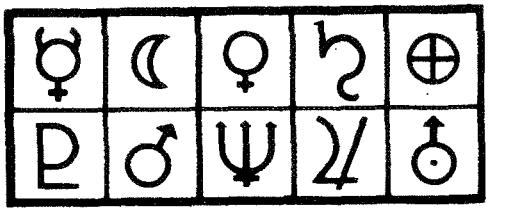

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CONTAMINATION CONTROL
A STATE-OF-THE-ART REVIEW

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Albuquerque, New Mexico

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CONTAMINATION CONTROL
A STATE-OF-THE-ART REVIEW*

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ABSTRACT

This report presents a review of the current status of contamination control, covering, in a general fashion, the areas of systems analysis, product design, facilities and equipment, monitoring, and personnel as they are related to contamination control.

November 1968

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CONTAMINATION CONTROL
A STATE-OF-THE-ART REVIEW

Introduction

Any dissertation on the state-of-the-art of a developing or rapidly expanding field is extremely time dependent and will generally be accurate for only a short period of time. It is with this thought in mind that the following status review is presented.

The Model

It seems appropriate to establish a frame of reference by considering the basic elements of contamination control, as shown in Figure 1. This model categorizes those elements that can become contaminated as "environments," and categorizes the contaminating influences as "contaminants."

For the purpose of this discussion, if any of the contaminants cause adverse effects on any of the environments, a contaminated condition occurs. This situation, in turn, brings about the need for some form of control which is called contamination control. So far as can be determined, this seemingly simple model can describe the entire field of contamination control in terms of contaminants and environments.

The basic model shown here can be easily expanded to provide details in any area of the discipline. For example, if one considers only particulate contaminants in air, this area includes everything from particulate air pollution to the air in a clean room. As suggested by Figures 2 and 3, the model may be further expanded to include control, monitoring, and other aspects of contamination control.

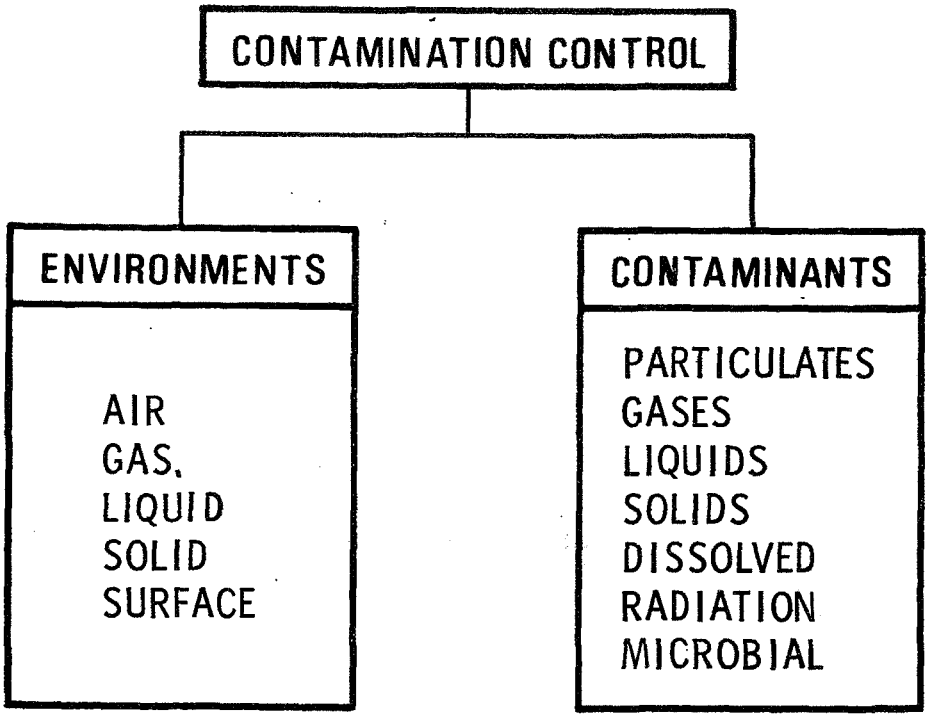


Figure 1

The Systems Approach

A technique that probably will become increasingly important is the systems approach to contamination control. Traditionally, we have attempted to solve individual contamination control problems as they arose. Rarely, to date, has anyone systematically considered all the factors affecting contamination control in a given situation. Whether it is called the systems approach, or such other names as systems analysis, systems engineering, or operations research, the result is essentially a determination of the importance and relationship of all elements affecting a specified result, and the probability of achieving that result. This may be an oversimplification, but it is a sufficient basis for applying the systems approach to contamination control.

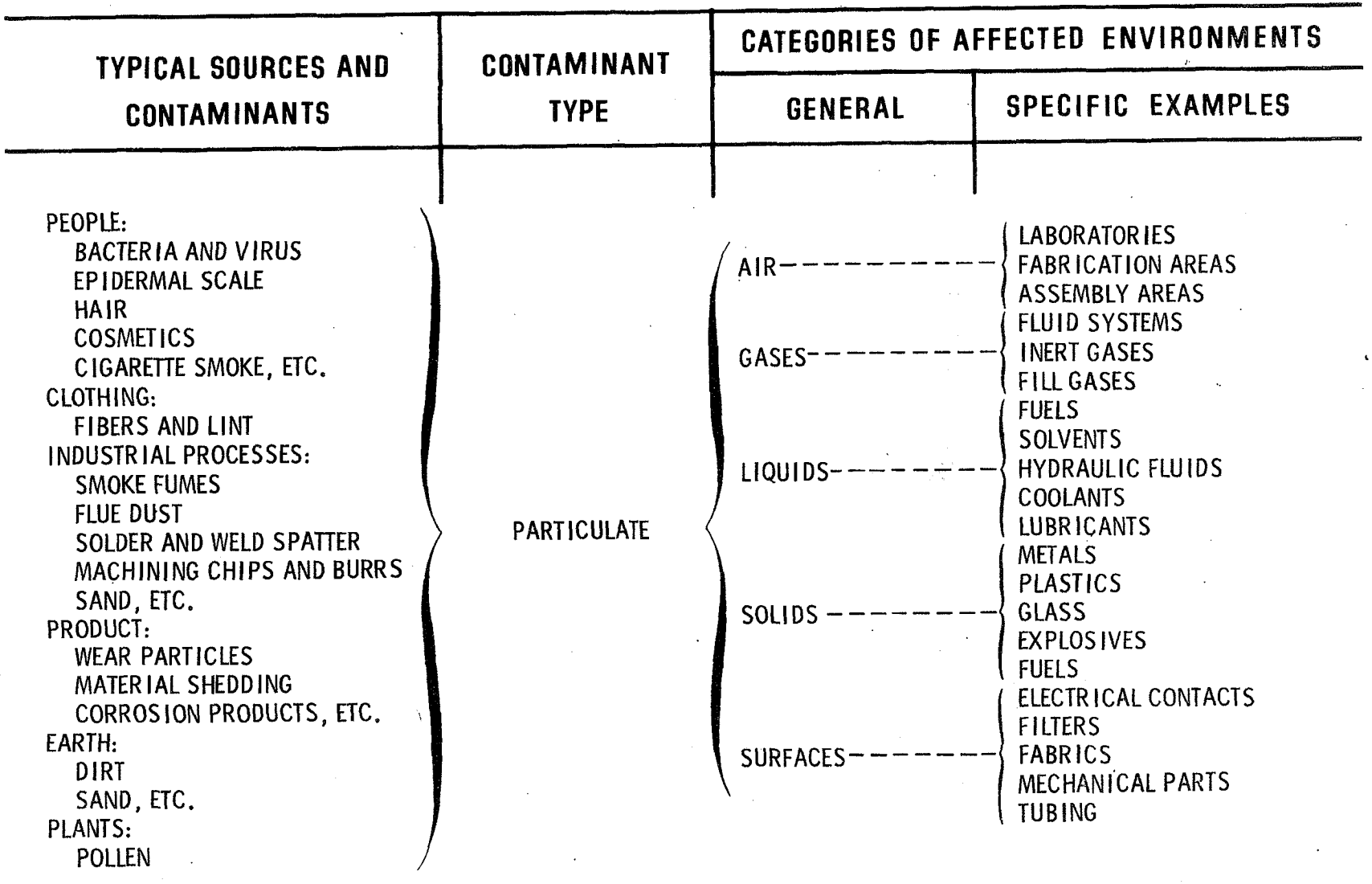
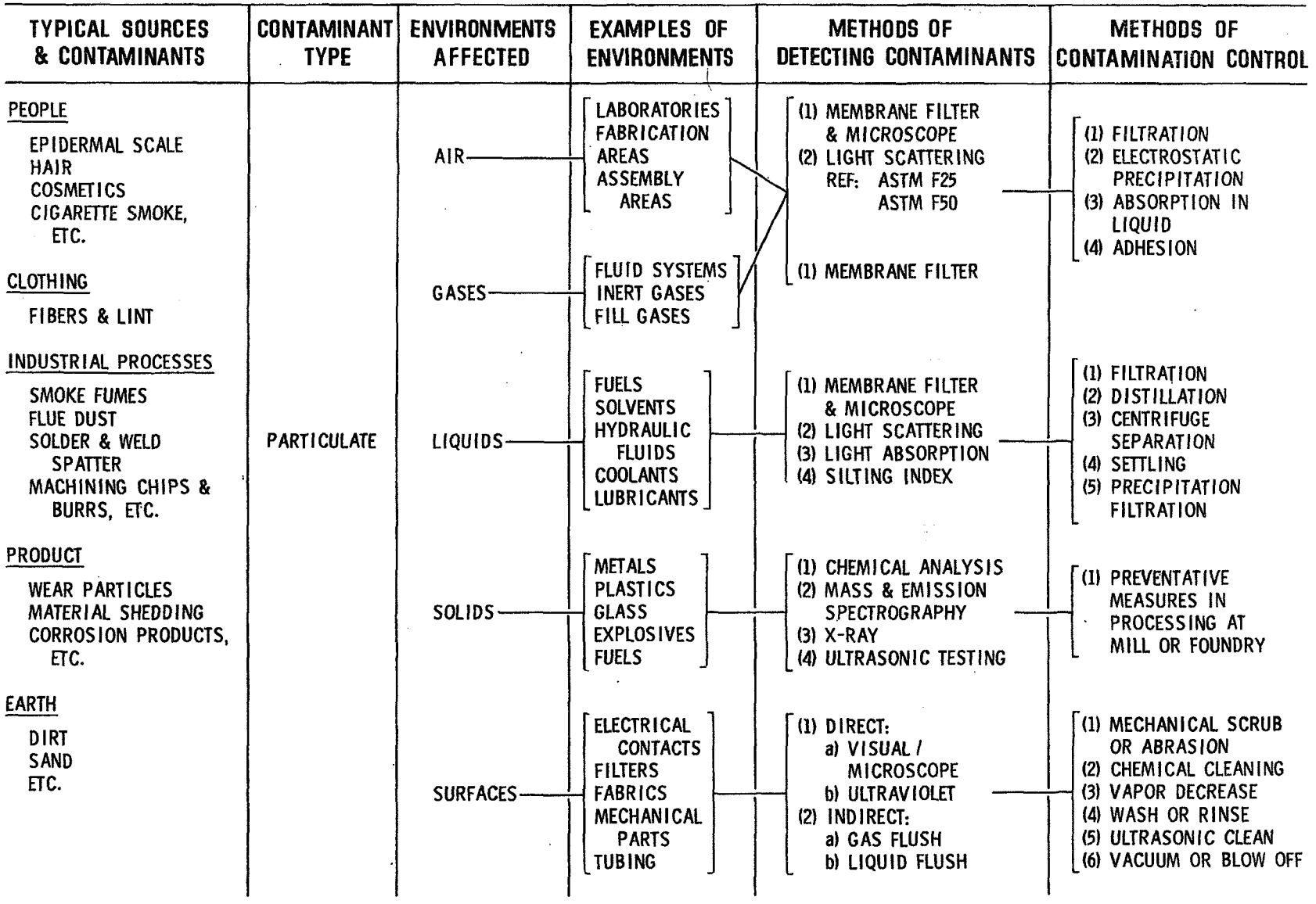

TYPICAL SOURCES AND CONTAMINANTS
CONTAMINANT TYPE
CATEGORIES OF AFFECTED ENVIRONMENTS
GENERAL
SPECIFIC EXAMPLES
PEOPLE:
BACTERIA AND VIRUS
EPIDERMAL SCALE
HAIR
COSMETICS
CIGARETTE SMOKE, ETC.
CLOTHING:
FIBERS AND LINT
INDUSTRIAL PROCESSES:
SMOKE FUMES
FLUE DUST
SOLDER AND WELD SPATTER
MACHINING CHIPS AND BURRS
SAND, ETC.
PRODUCT:
WEAR PARTICLES
MATERIAL SHEDDING
CORROSION PRODUCTS, ETC.
EARTH:
DIRT
SAND, ETC.
PLANTS:
POLLEN
PARTICULATE
AIR
LABORATORIES
FABRICATION AREAS
ASSEMBLY AREAS
GASES
FLUID SYSTEMS
INERT GASES
FILL GASES
LIQUIDS
FUELS
SOLVENTS
HYDRAULIC FLUIDS
COOLANTS
LUBRICANTS
SOLIDS
METALS
PLASTICS
GLASS
EXPLOSIVES
FUELS
SURFACES
ELECTRICAL CONTACTS
FILTERS
FABRICS
MECHANICAL PARTS
TUBING

Figure 2


TYPICAL SOURCES & CONTAMINANTS
CONTAMINANT TYPE
ENVIRONMENTS AFFECTED
EXAMPLES OF ENVIRONMENTS
METHODS OF DETECTING CONTAMINANTS
METHODS OF CONTAMINATION CONTROL
PEOPLE
EPIDERMAL SCALE
HAIR
COSMETICS
CIGARETTE SMOKE, ETC.
CLOTHING
FIBERS & LINT
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PLASTICS
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EXPLOSIVES
FUELS
ELECTRICAL CONTACTS
FILTERS
FABRICS
MECHANICAL PARTS
TUBING
(1) MEMBRANE FILTER & MICROSCOPE
(2) LIGHT SCATTERING
REF: ASTM F25
ASTM F50
(1) MEMBRANE FILTER
(1) MEMBRANE FILTER & MICROSCOPE
(2) LIGHT SCATTERING
(3) LIGHT ABSORPTION
(4) SILTING INDEX
(1) CHEMICAL ANALYSIS
(2) MASS & EMISSION SPECTROGRAPHY
(3) X-RAY
(4) ULTRASONIC TESTING
(1) DIRECT:
a) VISUAL / MICROSCOPE
b) ULTRAVIOLET
(2) INDIRECT:
a) GAS FLUSH
b) LIQUID FLUSH
(1) FILTRATION
(2) ELECTROSTATIC PRECIPITATION
(3) ABSORPTION IN LIQUID
(4) ADHESION
(1) FILTRATION
(2) DISTILLATION
(3) CENTRIFUGE SEPARATION
(4) SETTLING
(5) PRECIPITATION FILTRATION
(1) PREVENTATIVE MEASURES IN PROCESSING AT MILL OR FOUNDRY
(1) MECHANICAL SCRUB OR ABRASION
(2) CHEMICAL CLEANING
(3) VAPOR DECREASE
(4) WASH OR RINSE
(5) ULTRASONIC CLEAN
(6) VACUUM OR BLOW OFF

Figure 3

What are some of these elements that we should consider? In a general way they can be categorized in the following groups:

1. The Product itself, with its materials and configuration
2. The Cleanliness Level required
3. The Environments to which the product will be exposed
4. The Contaminants which might adversely affect the product
5. The Manufacturing or Processing involved
6. The Contamination Control Techniques which must be applied, and
7. The Monitoring or Verification of cleanliness.

Each of these groups can be expanded to include all of the known or expected variables affecting a given contamination control situation. This exercise in itself might be fairly simple if it were not for the complex interrelationships among the members of each group and among the different groups. An interesting example is man. He designs and builds a product; he develops and implements contamination control programs; he is definitely a part of the product environment; and, he is one of the most prolific contributors of contamination.

The systems approach may be applied in several different ways. It may take the form of informal discussions or it may involve preparation of sophisticated mathematical models. In any case, the results should be keener awareness of the total contamination control picture and what must be done to achieve a desired cleanliness level. And in order to realize the greatest benefit from the systems approach, it should be considered as part of the product design function.

Product Design

If available knowledge is to be fully utilized for contamination control purposes, some of it must be applied during design. For example, these are some of the parameters that must be considered:

1. Use of correct materials will prevent corrosion or galvanic action.
2. Materials should be chosen for minimum sloughing and wear characteristics.
3. Surface finish should be as smooth as practical.
4. As much as possible, blind holes and entrapment areas should be eliminated to facilitate cleaning.
5. Dimensions and tolerances should be as liberal as possible to prevent excessive wear.
6. Processes should be selected or designed for minimum contamination contribution.

These are the most obvious ways in which contamination control may be applied during the product design phase.

Facilities and Equipment

If each of you were asked to give your opinion of the state of present technology in contamination control facilities and equipment, we would have a variety of answers, each based on individual experience. Regardless of the diversity of opinion, however, we would probably all agree that some significant developments have been achieved:

1. Instruments are more sensitive, reliable, and repeatable.
2. We now have ultrasonic cleaners, which, if properly used, can produce predictable and highly satisfactory results.

3. Cleaning agents and equipment are capable of removing most soils or combinations of soils adequately.

4. Refinements and modifications in laminar airflow facilities have increased their usefulness and reliability, although the basic concept has remained virtually unchanged.

5. "Clean" packaging materials with low, or at least acceptable, sloughing tendencies have been developed.

6. Ancillary materials and equipment are available to supplement most contamination control activities.

Assuming that the foregoing statements are true--and this is a reasonable assumption--it would seem that the state of technology in facilities and equipment is such that contamination control needs can be met. Unfortunately, however, this is not always the case.

Additional applied research is badly needed in a number of areas. While some products will, under optimum conditions, meet the claims of their producers, many have limitations which severely curtail their usefulness. The desire to create sales appeal has too often overshadowed the need for well engineered products with a high degree of technical competency. We all recognize the necessity for making a profit, but poor design and poor workmanship must not be tolerated.

Monitoring

Monitoring for degrees of cleanliness, or, inversely, for the presence of contamination, is usually a precise and demanding operation, particularly as the size or quantity of the contaminant approaches minimum measurement limits. It is probably for this reason that the techniques and instrumentation for monitoring cleanliness have lagged behind other areas of the field.

This is not to imply that there have not been significant developments. Among these may be listed the solvent purity meter, more accurate and sensitive particle counting devices, the indium adhesion tester, and broader application of chromatography and spectrophotometry. Yet, we are still lacking a simple and accurate direct test for surface cleanliness. Nearly any known test for surface cleanliness has one or more of the following inherent disadvantages:

1. Results are subject to operator error and interpretation, and are therefore subjective and not repeatable.

2. Time needed for performing a test is excessive. (This is evident in laboratory set-up time and clean-up time for airborne particle measuring instruments.)

3. Cost of equipment is not compatible with usage and need. (This condition is usually present in a developing technology. Some improvement may be forthcoming as any one instrument comes into more common use.)

4. Equipment is complex and requires highly trained and experienced operators. (More and more, the laboratory technician is being replaced with the graduate engineer or specialist.)

5. A direct quantitative readout in standard units is not available. (This is a common failing of many test methods. In others, such as the cavitation meters, a quantitative readout is provided, but each manufacturer has developed his own units.)

6. The equipment is immobile and usually limited to laboratory type testing.

7. The equipment lacks sensitivity or resolution, or is difficult to calibrate. (In addition, some equipment does not provide a sufficient range capability.)

8. The test is limited to specified contaminants and will not measure others present. (This is particularly true for tests for atmospheric contaminants.)

9. The test is an indirect rather than a direct test. (On surfaces, it measures the amount of soil removed rather than the actual surface cleanliness.)

Obviously, much practical research remains to be accomplished and applied in cleanliness monitoring.

Personnel

It is hardly news to anyone in the contamination control field that people are great contributors of contamination. Normally, we think of body or garment particles in this regard; but a more important facet of this problem should be emphasized.

"Thinking Clean" is a state of mind. It is a condition which can be attained only through instruction, training, and good supervision. It requires an alert, receptive, and willing trainee as well as a full and honest explanation of why cleanliness is needed and what consequences may be expected if it is not achieved. Once attained, this conditioning must be nurtured and reinforced on a continuing basis.

Many of our contamination control problems arise from the acts of uninformed, inept, or poorly supervised operators. The value of a carefully developed procedure or a piece of expensive equipment can soon be nullified by a careless operator. In some industries, scrap losses can mount to unacceptable levels, and many companies are probably not realizing the full potential of their contamination control efforts. Perhaps personnel responsible for managing contamination control activities have been remiss in not providing or urging the adoption of professionally developed contamination control training programs.

With regard to personnel, the emergence of the so-called "contamination control specialist" should be mentioned. This concept, as it is presented here, was originally developed for the NASA Contamination Control Handbook. Most of the present personnel in the field represent a heterogeneous group of technical disciplines, including physics, chemistry, microbiology, and the various branches of engineering. This substantiates the premise that the contamination control specialist must also have a diverse academic and professional background. Academically, he should have at least a bachelor's degree in one of the physical sciences and preferably training in several of the related sciences. If he plans to work in the field of microbial contamination control, he should have academic training to a comparable level in one of the appropriate life sciences.

Experience and general knowledge requisites should be both product and contamination control oriented. In the product area, the contamination control specialist should be reasonably acquainted with design, assembly, testing, and packaging. In contamination control, he should be familiar with cleaning processes, contaminants, environments, monitoring, and instrumentation.

Anyone who has attained the status of a contamination control specialist represents a sizable investment in academic and professional training. Assuming that such an individual is needed and can be obtained, his services must be properly and fully utilized throughout the company with which he is associated. If he is relegated to the role of a technician, his value to the company will be seriously reduced. If, however, he is established in a peer position with the engineering and technical staff, he will be able to make a significant contribution to increased cost effectiveness and can provide maximum economic returns to his company in the following manner:

1. By reviewing proposed product designs, he should be able to deal effectively with potential contamination control problems and losses due to improper tolerances, configurations, and the use of materials.

2. He can determine appropriate product cleanliness levels and prescribe controls to achieve these levels at the optimum cost.

3. He can evaluate the effectiveness of various cleaning methods, equipment, and materials so that items purchased will be adequate but not excessive for the needs.

4. He can develop training programs and monitor adherence to established practices.

For the company that needs his services, the value of the contamination control specialist cannot be overemphasized. Colleges, universities, and others should encourage the development of likely candidates for this position.

Industry Applications

No appraisal of the state-of-the-art would be complete without a statement on the scope of contamination control activities and their effect on the national scene. The following examples from various companies and industries may be of interest.

1. In the medical field, Bataan Hospital in Albuquerque has a laminar flow operating room. The M. D. Anderson Hospital in Houston has installed its second clean room for cancer research. The Navy is constructing a hospital in South Carolina which will feature laminar flow operating, recovery, and intensive care rooms. And the Yale School of Medicine is considering laminar flow facilities for its premature and post-natal care areas.

2. A large electronics manufacturer has a very high capacity, recirculating, deionized water system to meet the cleanliness requirements for its semiconductor devices. In addition, it now has about 35 clean rooms, representing a total of nearly 120,000 square feet, two-thirds of which is laminar flow.

3. The NASA installation at Cape Kennedy, with its numerous fuel tanks and miles of lines, has a very sophisticated cleaning capability for flushing, purging, and drying this equipment in an effort to reduce the hydrocarbon concentration to the low parts-per-billion range.

4. There are over 40 clean rooms at one company in California, the largest of which is the assembly area for the command and service modules for the Apollo missions.

5. An aircraft company realized a substantial cost savings on one contract by using a Solvent Purity Meter to conduct 70,000 cleaning fluid tests for nonvolatile residue.

6. It has been estimated that over 2,000 clean benches are now in use in the pharmaceutical industry to improve the purity of drugs by eliminating airborne contamination and cross-contamination with other drugs.

7. In the clean environment industry itself, there are some 60 companies engaged in manufacturing clean rooms, benches, curtain units, and trailers. This industry was virtually nonexistent eight years ago.

Many more examples could be cited, but it should be sufficient to say that when you add other major areas such as the planetary quarantine of space vehicles, and air and water pollution control, you can begin to realize the scope and impact of applied contamination control.

Summary

In summarizing a review of this type, it is very easy to fall into the trap of saying, "A lot has been accomplished, but there is still much to be done." While this statement is not untrue, it falls far short of accurately expressing the current state-of-the-art in contamination control, how it was achieved, and what goals should be set up for the future. Perhaps the development of contamination control should be summarized as follows:

1. First, a need was recognized; a need for clean surfaces, clean air, clean liquids, and freedom from microbial contamination.

2. It was almost immediately evident that we needed the answers to many questions, such as: What are the forces involved in particle migration, retention, and removal? How can contaminants be eliminated, contained, or removed? How can small amounts of contamination be detected, both qualitatively and quantitatively?

3. In seeking the answers to these questions (some of which are still unanswered), we first attempted to modify existing techniques and equipment for application to contamination control needs.

4. Where adaptations of the existing technology were not readily found, completely new fields were explored. One result was the development of laminar airflow devices, which in turn brought about the founding of a new industry and new product lines for existing industries.

5. In many ways, the new products met some of our needs; in others, the products indicated a lack of understanding of the technical factors involved.

6. It became evident that contamination control was not a discipline in itself, but that it involved elements of many technical disciplines such as fine particle physics, surface chemistry, aerodynamics, electrical engineering, and mechanical engineering, to name a few.

Assuming that our evaluation of the current state-of-the-art of contamination control is reasonably accurate, what does the future hold for the field? Based on the events of the past and a visionary look into the future, the following postulations can be made.

1. The future course of contamination control, in terms of growth, will surely be determined by the need for such activities. With the increase in (1) microminiaturized electronic components, (2) control of infectious diseases, (3) planetary quarantine activities, and (4) control of water and air pollutants, this need seems assured.

2. The academic institutions will offer more and more courses directly concerning or related to contamination control. This will not come about rapidly, and no major course of study is envisioned for the near future. One of the greatest needs at this time is a basic college textbook.

3. There will be a greater recognition of the importance of contamination control, with the resulting emergence of the contamination control specialist.

4. With the amount of research being conducted in the field of instrumentation, there should be a marked improvement in monitoring sensitivity and techniques.

5. And last, contamination control is now emerging as a discipline in itself. It is assuming a deserved professional status. If the field continues to attract competent people, it will be a rising and dynamic force which touches nearly all aspects of our lives, and particularly the lives of future generations.